Document made available under the Patent Cooperation Treaty (PCT)

International application number: PCT/EP04/053526

International filing date: 16 December 2004 (16.12.2004)

Document type: Certified copy of priority document

Document details: Country/Office: GB
Number: 0329243.0
Filing date: 17 December 2003 (17.12.2003)

Date of receipt at the International Bureau: 31 January 2005 (31.01.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)

63324 WO1
PCT/EP2004/053526

The Patent Office

INVESTOR IN PEOPLE

PCT/EP2004/053526

EPO - DG 1

13. 01. 2005

(55)

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

I also certify that the attached copy of the request for grant of a Patent (Form 1/77) bears a correction, effected by this office, following a request by the applicant and agreed to by the Comptroller-General.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

Signed

Dated 30 December 2004

PCT/EP2004/053526 18DEC03 E860225-8 D00060
P01/7700 0.00-0329243.0 CHEQUE

1/77

P ...nts Form 1/77

Patents Act 1977
(Rule 16)

The Patent Office

THE PATENT OFFICE G 17 DEC 2003 LONDON

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

The Patent Office

Cardiff Road
Newport
South Wales
NP10 8QQ

1. Your reference

NJH/FP6166136

2. Patent application number
(The Patent Office will fill this part in)

0329243.0 17 DEC 2003

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

~~THALES PLC~~ Thales UK PLC
2 DASHWOOD LANG ROAD
THE BOURNE BUSINESS PARK
ADDLESTONE, NR WEYBRIDGE
SURREY KT15 2NX

GT
F1/77
4.11.04

Patents ADP number *(if you know it)*

~~8352502003~~

If the applicant is a corporate body, give the country/state of its incorporation

UNITED KINGDOM 8973844001

4. Title of the invention

APPARATUS AND METHODS FOR ACTUATION

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

MEWBURN ELLIS
York House
23 Kingsway
London WC2B 6HP

Patents ADP number *(if you know it)*

109006 ✓

6. Priority: Complete this section if you are declaring priority from one or more earlier patent applications, filed in the last 12 months.

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. Divisionals, etc: Complete this section only if this application is a divisional application or resulted from an entitlement dispute (see note f)

Number of earlier UK application	Date of filing *(day / month / year)*

8. Is a Patents Form 7/77 (Statement of inventorship and of right to grant of a patent) required in support of this request?

YES

Answer YES if:

a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.

Otherwise answer NO (See note d)

9. Accompanying documents: A patent application must include a description of the invention. Not counting duplicates, please enter the number of pages of each item accompanying this form:

Continuation sheets of this form	0
Description	33
Claim(s)	9
Abstract	1
Drawing(s)	3 + 3

10. If you are also filing any of the following, state how many against each item.

Priority documents	0
Translations of priority documents	0
Statement of inventorship and right to grant of a patent (Patents Form 7/77)	1
Request for a preliminary examination and search (Patents Form 9/77)	1
Request for a substantive examination (Patents Form 10/77)	0
Any other documents (please specify)	0

11. I/We request the grant of a patent on the basis of this application.

Signature(s) Mewburn Ellis Date 16 DECEMBER 2003

12. Name, daytime telephone number and e-mail address, if any, of person to contact in the United Kingdom

Nigel J. HACKNEY
0161 247 7722

Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

Notes

a) If you need help to fill in this form or you have any questions, please contact the Patent Office on 08459 500505.

b) Write your answers in capital letters using black ink or you may type them.

c) If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.

d) If you have answered YES in part 8, a Patents Form 7/77 will need to be filed.

e) Once you have filled in the form you must remember to sign and date it.

f) Part 7 should only be completed when a divisional application is being made under section 15(4), or when an application is being made under section 8(3), 12(6) or 37(4) following an entitlement dispute. By completing part 7 you are requesting that this application takes the same filing date as an earlier UK application. If you want the new application to have the same priority date(s) as the earlier UK application, you should also complete part 6 with the priority details.

Apparatus and methods for actuation

The present invention relates to apparatus and methods of actuation, particularly, though not exclusively, to actuation and actuators for use in providing simulated motion in a vehicle simulator machine.

Motion systems commonly used for providing simulated motion in a vehicle simulator machine comprise a group of hydraulic actuators arranged together to support a vehicle simulator platform and operable to provide six degrees of freedom of movement of that platform. An example of a motion system providing six degrees of freedom of motion for an aircraft simulator platform is illustrated in Figure 1. The motion system 1 comprises a group of six linear actuators 2 each separately operable and each coupled to a motion platform 3 by an articulated joint 4 which permits movement of the joint 4, and the motion platform 3 connected to it, in any of six degrees of freedom in response to the linear extension/retraction of any number of the six hydraulic actuators 2.

In motion systems using hydraulic actuators, such as illustrated in Figure 1 for example, each hydraulic actuator is typically controlled by a servo valve which

regulates the transfer of pressurised fluid into an out of the hydraulic chambers of the hydraulic actuators. In use, hydraulic fluid is continuously pumped to the hydraulic chambers of each actuator of the motion system, via the servo valve(s), at the maximum pressure available to the motion system, irrespective of the force output the actuators are intended to supply. This makes very inefficient use of the energy supplied to the motion system as a whole. Moreover, such hydraulic motion systems typically require a remote Hydraulic Power Unit (HPU) which is not only noisy but also requires a dedicated cooling system (much heat being generated due to the loss of input energy associated with this type of system.

Because of the heat and noise generated by HPUs, and the space required for their associated cooling units, HPUs are typically located in a room separate from the motion system they serve. A consequence of this remote location is the need for long hydraulic fluid conduits which place the HPU in fluid communication with the actuators of the motion system in question. In addition, large capacity pressurised oil accumulators are mounted close to each actuator to meet peak flow demand. The provision of such conduits is expensive and highly inflexible and inconvenient. Large volumes of hydraulic fluid must be

employed in order to fill the relatively large combined volume of the HPU fluid chamber(s), the chambers of the hydraulic actuators served by the HPU, and the conduits connecting the former to the latter. This is undesirable.

Motion systems employing electric actuators typically require actuators which are large, heavy, complex and expensive. Such actuators are very difficult, if not effectively impossible, to service when in situ within a motion system.

The present invention aims to overcome at least some of the aforementioned deficiencies in the prior art.

As is well known in the art, a hydraulic actuator may have an actuator chamber containing a moveable actuator piston and an actuator rod connected to the actuator piston and retractably extendable from the actuator chamber.

In a "double-acting" chamber, the actuator chamber and actuator piston define an extend chamber and a retract chamber separated from the extend chamber by the actuator piston. In a "differential" actuator, the actuator rod extends through the retract chamber only, and not through

the extend chamber. The actuator is powered to extend its actuator rod by transferring fluid into the extend chamber and out of the retract chamber to cause the actuator piston to move to increase the volume of the extend chamber and thereby decrease that of the retract chamber. Retraction of the actuator rod is powered by a reverse movement of fluid.

At its most general, the present invention proposes supplying fluid simultaneously to both the extend and retract chambers of a double-acting differential actuators at substantially the same pressure. The mutual pressure is most preferably chosen to be sufficient to enable the actuator to support its load. Extension or retraction of the actuator rod may then be achieved simply by moving the pressurised fluid into/out-of the extend/retract chambers, or the retract/extend chambers, respectively.

Consequently, the fluid pressure of the supplied fluid need only be sufficient to support the actuator load and no more. Furthermore, by supplying fluid at substantially the same pressure to both the extend and retract chambers of the actuator, one may simply reversibly transfer fluid from either one of those chambers to the other of those chambers as the volume of

one chamber contracts while the other expands during movement of the actuator rod (and piston). Since little or no pressure differential will exist as between the mutually pressurised extend and retract chambers of the actuator, this fluid transfer may be done with relatively little effort. This is an energy efficiency.

The fluid transfer in each or either case may be affected by means other than the operation of valves to control the transfer of high-pressure fluid. Most preferably, separate reversible hydraulic pumps are used for such fluid transfer demanding lower energy inputs than are required in existing prior art systems.

In this way, the need for a remote HPU is obviated. By using fluid transfer means (e.g. hydraulic pumps) other than valves metering high-pressure fluid, one may avoid the heat and noise generated, and amount of energy consumed, in generating high-pressure hydraulic fluid otherwise required for serving the hydraulic actuators of a motion system (or any other system). The supply of hydraulic fluid to the actuators of the motion system may therefore be local rather than remote since the reasons for, and consequences or, remote fluid provision (as in a HPU) are no longer present.

Accordingly, in a first of its aspects, the present invention may provide an actuator having:

an actuator chamber containing a moveable actuator piston and an actuator rod connected to the actuator piston and retractably extendable from the actuator;

the actuator chamber and actuator piston defining an extend chamber and a retract chamber separated from the extend chamber by the actuator piston such that the actuator rod extends through the retract chamber;

a fluid supply means arranged to supply fluid simultaneously to both the extend and retract chamber at substantially the same pressure and to reversibly transfer said pressurised fluid between the extend and retract chambers of the actuator.

Of course, the fluid supply means is most preferably operable to control the mutual fluid pressure of the fluid supplied thereby to the extend and retract chambers to be sufficient to enable the actuator to support a load applied to the actuator in use. Preferably, the fluid supply means is arranged to reversibly transfer aforesaid pressurised fluid between the extend and retract chambers of the actuator, and to separately and independently reversibly transfer aforesaid pressurised fluid between the extend chamber and a pressurised fluid store means. Thus, movement of the actuator piston within the actuator

chamber of the differential actuator results in different rates of volumetric change as between the extend and retract chambers. Accordingly, the fluid supply means is preferably arranged to transfer between the extend and retract chambers volumes of pressurised fluid substantially equal to a change in the volume of the retract chamber. The fluid supply means is most preferably arranged to simultaneously transfer to and from the extend chamber volumes of pressurised fluid substantially equal to the change in the volume of the extend chamber less the concurrent change in the volume of the retract chamber.

Preferably, the actuator includes a first fluid transfer means in fluid communication with the extend chamber and the retract chamber and arranged to transfer therebetween volumes of fluid substantially equal in magnitude to changes in the volume of the retract chamber resulting from movement of the actuator piston within the actuator chamber;

and a second fluid transfer means in fluid communication with the extend chamber and operable to transfer to and from the extend chamber volumes of fluid substantially equal in magnitude to the difference between said changes in the volume of the retract chamber

and concurrent changes in the volume of the extend chamber.

Thus, a double-acting actuator chamber may be provided in which the actuator is powered by transferring fluid directly from the extend chamber to the retract chamber (or vice versa) together with a concurrent transfer of fluid from (or to) the extend chamber matching the overall change in the combined volume of the extend and retract chambers due to extension/retraction of the actuator rod. This separate fluid transfer arrangement has been found to require much lower energy inputs to operate as compared to the existing method of valves metering high-pressure fluid to/from an actuator chamber.

Most preferably, one or both of the first and second fluid transfer means employs a fluid/hydraulic pump or pumps. The fluid transfer means may employ two pumps each operable to pump fluid in one of two opposite directions thereby, in combination, forming a bi-directional pump. Alternatively, the first and/or second fluid transfer means is preferably a single reversible fluid pump. Preferably, the second fluid transfer means is a reversible (or bi-directional) second fluid pump whereby the second pump is arranged to pump fluid at a volumetric rate determined according to the volumetric

pump rate of the first pump. Preferably, volumetric rate of the second pump is determined according to that of the first pump such that transfer of fluid from (or to) the extend chamber matches the overall change in the combined volume of the extend and retract chambers due to extension/retraction of the actuator rod.

Where the actuator chamber, actuator piston and those parts of the actuator rod within the actuator chamber define a retract chamber of substantially annular volume, the first and second pumps are preferably arranged such that the ratio of the concurrent volumetric pump rates of the second and first pumps is substantially equal to the ratio of: changes in the volume of those parts of the actuator rod within the retract chamber; and, the corresponding changes in the annular volume of the retract chamber. This ensures that concurrent changes in the volumes of the extend and retract chambers are matched to the volumes of fluid being transferred thereto or therefrom by the separate first and second pumps.

Most preferably, the fluid supply means is operable to supply fluid to the extend and retract chambers of the actuator at a pressure sufficient to enable to support at least the static mass of the actuator load (e.g. vehicle simulator platform). Most preferably, the actuator is

operable to control the fluid transfer means to transfer pressurised fluid to enable the actuator to support/drive inertial loads applied to the actuator in use (e.g. inertial forces arising through movement of a vehicle simulator platform). Such transfer of pressurised fluid by the fluid transfer means need only be done "on demand" and the fluid transfer means need not itself generate the pressure present within the fluid it transfers which is needed to support the static load of the actuator.

Any tendency of the actuator rod to overshoot the position demanded of it would result in an overshoot in the internal position of the actuator piston within the actuator chamber. Consequently, more pressurised fluid would be urged to leave the extend chamber than desired. The present invention may provide a mass counterbalance function without the use of a valve, but rather, by use of the application of back-pressure at the fluid output from the second fluid transfer means from which fluid is output in response to contraction of the extend chamber, so as to partially resist the output of that fluid therefrom. In this way, the tendency to over-retraction of the actuator rod, which corresponds with an urging of fluid from the extend chamber, is at least partially resisted and is thereby damped or counterbalanced.

Furthermore, when a fluid pump is employed as the second fluid transfer means to transfer fluid from the extend chamber, the urging of an ejection of an excess of fluid from the extend chamber (a result of "overshoot") would urge the second fluid transfer means to transfer fluid (i.e. pump) greater than the rate at which the actuator controls the transfer means to operate. The actuator is arranged to resist this urging and thereby to provide a mass counter-balance effect by applying a torque to the drive motor of the pump of the second fluid transfer means which opposes the torque applied thereto by the urging pressure from the extend chamber. In addition, the back-pressure applied to the output of the second fluid transfer pump also applied a similarly resistive torque to the pump by urging the pump to back-drive in response to the back-pressure.

Preferably, the second fluid transfer means is in fluid communication with a fluid vessel and is arranged to transfer fluid from the extend chamber to the fluid vessel and vice versa, wherein the fluid vessel is arranged to hold fluid received thereby from the second fluid transfer means in a state sufficiently pressurised to generate a back-pressure upon the second fluid transfer means which partially resists the flow of fluid from the second fluid transfer means to the fluid vessel.

For example, the fluid vessel may be a fluid conduit connecting the second fluid transfer means in fluid communication with, and terminating at, a hydraulic accumulator.

The second transfer means is most preferably a reversible fluid pump and said fluid vessel is arranged to generate said back-pressure being sufficient to urge the reversible fluid pump of the second transfer means to back-drive thereby to urge the pump to operate to pump fluid from the fluid vessel to the extend chamber. In this way, the over-retraction of the actuator rod, which corresponds with an over-contraction in the volume of the extend chamber, is at least partially resisted and is thereby damped or counterbalanced.

Thus, an inherent mass counterbalance function is provided without the use of a counterbalance valve.

The fluid vessel is preferably operable to be in fluid communication with said first fluid transfer means via said second fluid transfer means. This enables losses of fluid, through leakage and the like, from either the retract or extend chamber, of from either of the first

and second fluid transfer means to be replenished easily with fluid from the fluid vessel.

Furthermore, the fluid supply means of the actuator may include a fluid reservoir for use in supplying pressurised fluid to the fluid vessel, the first fluid transfer means, the second fluid transfer means, and the actuator chamber.

The fluid supply means of the actuator is arranged to supply fluid at an equal pressure to both sides of the actuator piston. The actuator behaves as a simple "displacement" (or "single acting") actuator, and generates a force equal to the pressure of the supplied fluid multiplied by the difference in area between the head-side (extend chamber side) and rod-side (retract chamber side) of the actuator piston (i.e. the area of the rod-side piston surface taken up by the actuator rod).

Where, in the present invention, there exists a leakage path of pressurised fluid from/into the retract chamber of the extend chamber of the actuator, the result may be an undesired pressure differential as between the preferably equally pressurised extend and retract chambers of the actuator and a consequent movement of the

actuator rod. Preferably, the fluid transfer means is arranged to maintain a given desired static position of the actuator rod by transferring pressurised fluid to-from the extend and/or retract chamber as required to maintain the mutual fluid pressure therein and thereby to maintain the given desired static position of the actuator rod.

The present invention, in a second of its aspects, may provide a motion platform for a vehicle motion simulator machine including an actuator according to the invention in its first aspect including none some or all of the variants and preferable features discussed above.

Furthermore, the invention is a third of its aspects may provide a vehicle motion simulator including a motion platform according to the invention in its second aspect.

It is to be understood that the invention is any of its first, second or third aspects represents the implementation of a method of actuation, or vehicle motion simulation respectively.

Accordingly, in a fourth of its aspects, the present invention may provide a method of actuation for use with an actuator having an actuator chamber containing a

moveable actuator piston and an actuator rod connected to the actuator piston and retractably extendable from the actuator, the actuator chamber and actuator piston defining an extend chamber and a retract chamber separated from the extend chamber by the actuator piston such that the actuator rod extends through the retract chamber, the method including:

supplying fluid simultaneously to both the extend and retract chamber at substantially the same pressure and reversibly transferring said pressurised fluid between the extend and retract chambers of the actuator.

Most preferably, the method includes controlling the mutual fluid pressure of the fluid supplied to the extend and retract chambers to be sufficient to enable the actuator to support a load applied to the actuator in use.

Preferably, the method includes reversibly transferring aforesaid pressurised fluid between the extend and retract chambers of the actuator, and separately and independently reversibly transferring aforesaid pressurised fluid between the extend chamber and a pressurised fluid store means.

Accordingly, the method preferably includes transferring between the extend and retract chambers volumes of pressurised fluid substantially equal to a change in the volume of the retract chamber. Most preferably includes simultaneously transferring to and from the extend chamber volumes of pressurised fluid substantially equal to the change in the volume of the extend chamber less the concurrent change in the volume of the retract chamber.

Preferably, the method includes transferring between the extend chamber and the retract chamber volumes of fluid substantially equal in magnitude to changes in the volume of the retract chamber resulting from movement of the actuator piston within the actuator chamber; and,

transferring to and from the extend chamber volumes of fluid substantially equal in magnitude to the difference between said changes in the volume of the retract chamber and concurrent changes in the volume of the extend chamber.

Preferably, fluid is transferred between the extend chamber and the retract chamber by the reversible pumping thereof at a first volumetric pump rate, and fluid is transferred to and from the retract chamber by the reversible pumping thereof at a second volumetric pump

rate determined according to the first volumetric pump rate.

Preferably, the actuator chamber, actuator piston and those parts of the actuator rod within the actuator chamber define a retract chamber of substantially annular volume, whereby the ratio of the concurrent second and first volumetric pump rates is substantially equal to the ratio of: changes in the volume of those parts of the actuator rod within the retract chamber; and, the corresponding changes in the annular volume of the retract chamber.

Most preferably, the method includes supplying fluid to the extend and retract chambers of the actuator at a pressure sufficient to enable to support at least the static mass of the actuator load (e.g. vehicle simulator platform). Most preferably, the method further includes transferring pressurised fluid to enable the actuator to support/drive inertial loads applied to the actuator in use (e.g. inertial forces arising through movement of a vehicle simulator platform).

The method preferably includes applying a back-pressure at the fluid output from the second fluid transfer means from which fluid is output in response to contraction of

the extend chamber, so as to partially resist the output of that fluid therefrom.

The method preferably includes providing a mass counter-balance effect by providing a reversible fluid pump for implementing the aforesaid second volumetric pumping rate, and applying a torque to the drive motor of the fluid pump which opposes the torque applied thereto by the fluid pressure from the extend chamber felt at the fluid pump.

The method preferably includes holding fluid transferred from, or to be transferred to, the extend chamber in a state sufficiently pressurised to generate a back-pressure which partially resists the transfer of fluid from the extend chamber.

More preferably, the method includes providing the aforesaid reversible fluid pump arranged to perform said transfer of fluid to and from the extend chamber by pumping said fluid, and generating said back-pressure to be sufficient to urge the reversible fluid pump to back-drive thereby to urge the pump to operate to pump said held fluid to the extend chamber.

In a fifth of its aspects the present invention may provide a method of simulating motion in a vehicle simulator machine using the method of actuation according to the invention in its fourth aspect.

Non-limiting examples of the invention shall now be described with reference to the accompanying drawings in which:

Figure 1 illustrates a system of actuators providing a motion system for a vehicle motion simulator;

Figure 2 schematically illustrates the relative volumetric fluid pumping rates of a first and second reversible hydraulic pumps;

Figure 3 illustrates a hydraulic actuator system with a hydraulic accumulator;

Figure 4 illustrates a hydraulic actuator system including a fluid pre-charging system;

Figure 5 illustrates schematically the rod-side (retract chamber) and head-side (extend chamber) piston areas of a double-acting differential actuator chamber.

Referring to Figure 5 there is schematically illustrated the internal components of a double-acting differential actuator chamber of the present invention. The actuator chamber comprises a chamber split by a piston into an extend chamber and a retract chamber. An actuator rod

extends from the "rod-side" of the piston through the retract chamber. No such rod extends through the "head-side" of the extend chamber thereby rendering the actuator "differential" in the sense that the available head-side piston area A upon which fluid within the extend chamber of pressure P_H can act, is greater than the available head-side piston area (A-a) upon which fluid within the retract chamber of pressure P_R can act. The difference in area is the area "a" of the rod-side piston taken-up by the actuator rod.

Consider the actuator of Figure 5 supporting a load W. In equilibrium, the balance of load and pressures gives:

$$P_H A = P_R (A - a) + W$$

Setting the rod-side and head-side pressures to be equal (i.e. $P_H=P_R$) gives:

$$P_H = P_R = \frac{W}{a}$$

Thus, the load W is supported by applying equal fluid pressure to both the rod-side and head-side of the actuator, the mutual pressure being equal to the magnitude of the load force W supported by the actuator, divided by the area of the actuator rod. It will be appreciated that equal extend and return forces (magnitudes P(A-a) and Pa respectively) are achieved when A=2a.

Referring to figure 3 there is shown a schematic illustration of an actuator system 5 according to an embodiment of the present invention. The actuator system 5 includes an actuator cylinder 6 possessing an internal cylindrical actuator chamber containing an actuator piston 9 to which is connected an actuator rod 8. The actuator piston is formed to closely, but slideably, fit against the internal cylindrical walls of the actuator chamber which oppose it so as to partition the actuator chamber into a retract chamber 7 and an extend chamber 10 separated from the retract chamber 7 by the actuator piston. The piston is able to slide along the cylindrical against the internal walls of the actuator chamber along the cylindrical axis thereof so as to produce changes in the volumes of the extend and retract chambers of the actuator.

The actuator rod 8 extends from the actuator piston 9 through the retract chamber along the cylindrical axis of the actuator chamber, through an end wall 19 thereof and outwardly of the actuator cylinder 6. The actuator cylinder forms a sealing fit against those parts of the actuator rod which extend through the end wall 19 of the retract chamber.

Sliding movement of the actuator piston within the actuator chamber results in a corresponding retraction or extension of the actuator rod to/from the actuator cylinder 6 as the piston is slid away from or towards the end wall 19 of the retract chamber 19 through which the actuator rod 8 extends. Thus, control of the position of the actuator piston 9 within the "double acting" actuator chamber (7, 10) of the actuator controls the retraction/extension of the actuator rod 8.

A first fluid transfer means, in the form of a reversible first hydraulic pump (A), is placed in fluid communication with the extend chamber and the retract chamber via a fluid conduit 12 extending from the retract chamber to a fluid port A1 of the first pump, and via a further fluid conduit (13, 14) extending from a second fluid port A2 of the first pump and terminating at the extend chamber 10 of the actuator. The first pump is arranged to transfer, between the extend and retract chambers via the fluid conduits, volumes of fluid substantially equal in magnitude to changes in the volume of the retract chamber resulting from movement of the actuator piston within the actuator chamber.

A second fluid transfer means is provided in the form of a reversible hydraulic pump (B) in fluid communication

with the extend chamber 10 via a fluid conduit (14, 15) extending from the extend chamber to a fluid port B2 of the second pump. The second pump is operable to transfer to and from the extend chamber volumes of fluid substantially equal in magnitude to the difference between said changes in the volume of the retract chamber and concurrent changes in the volume of the extend chamber. Any suitable type of fluid pump may be used, such as would be readily apparent to the skilled person for example.

The actuator is powered by transferring fluid directly from the extend chamber to the retract chamber (or vice versa) together with a concurrent transfer of fluid from (or to) the extend chamber matching the overall change in the combined volume of the extend and retract chambers due to extension/retraction of the actuator rod. This separate fluid transfer arrangement is performed by the pumping of fluid using the reversible first and second pumps (A, B) to control the rate and direction of fluid flow to and from the extend and retract chambers of the actuator.

The two reversible pumps are powered by a common electrical servo motor 11 which is suitably geared to

ensure that the second fluid pump B pumps fluid at a volumetric rate determined according to that of the first pump such that transfer of fluid from (or to) the extend chamber matches the overall change in the combined volume of the extend and retract chambers due to extension or retraction of the actuator rod.

This arrangement may employ any type of pump. Ideally the extend chamber volume will be twice the retract chamber volume (i.e. A/a=2, see Figure 5), but where there is a volumetric deviation from this ideal state one may either use gearing to match the outputs from two equal pumps to the non-ideal actuator displacement, or have specially matched pumps, or manage small (e.g. less than 5%) differences with the leakage flow into the retract chamber from the hydrostatic bearing feed 32 in figure 4.

Figure 2 schematically illustrates the relationship between the pump rates of the first and second pumps (A, B). The actuator chamber, actuator piston 9 and those parts of the actuator rod 8 within the actuator chamber define a retract chamber 7 of substantially annular volume V_A which is available for occupation by hydraulic fluid. Correspondingly, those parts of the actuator rod within the retract chamber occupy a volume V_B of the retract chamber which is unavailable for occupation by

hydraulic fluid. The first pump A and second pump B are arranged such that the ratio of the concurrent volumetric pump rates (R_B/R_A) of the second (B) and first (A) pumps is substantially equal to the ratio (V_B/V_A) of: changes in the volume (V_B) of those parts of the actuator rod within the retract chamber; and, the corresponding changes in the annular volume (V_A) of the retract chamber (i.e. $R_B=(V_B/V_A)R_A$).

Consequently, concurrent changes in the volumes of the extend and retract chambers are matched to the volumes of fluid being transferred thereto or therefrom by the separate first and second pumps.

Referring to figure 3, the actuator system illustrated therein possesses a hydraulic accumulator 17 having a pressurised fluid storage chamber 18 in fluid communication, via a fluid conduit 16, with the fluid port B1 of the second pump B remote from the extend chamber 10 of the actuator. The second pump is a reversible fluid pump and the hydraulic accumulator is arranged to receive/supply fluid from/to the second fluid pump in response to contraction/expansion of the extend chamber. The accumulator generates a back-pressure within the fluid supplied by it to the second fluid pump B which is sufficient to urge the reversible second fluid

pump to back-drive thereby to urge the pump to operate to pump fluid from the accumulator to the extend chamber (this also assists the mutually-driven [common motor 11] pump A to transfer fluid from the retract chamber to the extend chamber). In this way, the over-retraction of the actuator rod, which corresponds with an over-contraction in the volume of the extend chamber, is at least partially resisted and is thereby damped or counterbalanced. A mass counterbalance function is thereby provided by use of the application of pressure to hydraulic fluid output from fluid port B1 of the second pump B, this output fluid being fluid transferred from the extend chamber 10 by the second pump B resulting in retraction of the actuator rod 8.

Furthermore, the pressurised of fluid at the fluid port B1 of the second pump remote from the extend chamber also partially resists the output of fluid from the fluid port B1 to the accumulator chamber 18 communicating with that port. In this way, the tendency to over-retraction of the actuator rod, which corresponds with an urging of fluid from the extend chamber, is at least partially resisted and is thereby damped or counterbalanced.

The hydraulic accumulator 17 is in fluid communication with the first fluid pump A via the second fluid pump B

and the intermediate fluid conduits (13,14,15) connecting the first and second pumps mutually to the extend chamber 10. Losses of fluid, through leakage and the like, from either the retract or extend chamber, of from either of the first and second fluid pumps may be replenished easily with fluid from the hydraulic accumulator 17.

The direction and rate of fluid flow from/to the extend and retract chambers of the actuator is controlled by the direction and rate of pumping of the first and second reversible pumps (A, B). These are powered by the servo motor 11 which delivers power concurrently to each of the first and second pumps via a transmission system (not shown) suitably geared to put effect to the different concurrent volumetric pump rates of the two pumps in use.

Figure 4 illustrates a further embodiment of the present invention comprising all of the features of the embodiment illustrated in figure 3. Like elements in figures 3 and 4 share a common reference symbol.

The actuator system of figure 4 includes a fluid supply collectively denoted 20, which is arranged to be in fluid communication with and to supply pressurised fluid to the hydraulic accumulator 17, the first fluid pump A, the second fluid pump B, and the hydrostatic bearing of the

actuator cylinder 6. The fluid supply includes a fluid reservoir 21 and a fluid conduit 27 which places the fluid reservoir 21 in fluid communication directly with the fluid conduit 16 which connects the hydraulic accumulator in fluid communication with the fluid port B1 of the second pump B remote from the extend chamber of the actuator. In this way, the fluid reservoir is operable to be placed in fluid communication with the rest of the actuator fluid circuit.

Included within the fluid supply 20 is a pre-charge system 22 arranged to pressurise fluid supplied by the fluid supply 20 to the rest of the actuator system. The pre-charge system includes a pre-charge fluid pump 24 powered by an electrical servo motor 23 and arranged within the fluid conduit 27 of the fluid supply system to transfer fluid from the fluid reservoir 21 and into and along the fluid conduit 27 of the fluid supply system to the other parts of the actuator fluid circuit with which the fluid reservoir is in fluid communication. Arranged in series along the fluid conduit 27 of the fluid supply system, subsequent to the pre-charge fluid pump 24 thereon, are a fluid filter 25 for filtering hydraulic fluid output by the pre-charge pump 24, and a one-way valve 26 arranged to receive filtered hydraulic fluid output by the fluid filter 25 and to pass such filtered

fluid to (but not admit fluid from) the up-stream section of the fluid conduit, and a landing valve unit 28 arranged to receive filtered fluid output by the one-way valve 26.

The landing valve unit 28 is solenoid operated so that either software or manual (emergency or maintenance) switching can take control of the landing sequence, i.e. returning the simulator to its rest state - all actuators fully retracted - from some previous 'flying state' so that crew members may disembark.

Essentially the landing valve is a solenoid-operated check-valve with a one-way flow restrictor applied to the oil being exhausted from the actuator chamber 10. In normal use, neither the check-valve nor flow restrictor are in the fluid circuit, and the landing valve permits free flow from pump 24 and maintains the drain line 29 closed.

The landing valve is often necessary as there is full mass counter balance and in the event of power loss the stored pressure in the accumulator will maintain the 'flying' height of the simulator with the danger that pressure in one or more of the 6 motion actuators may lose pressure before the rest, resulting in potentially

extreme listing over an extended period before finally settling. As a second function, the landing valve will fully deplete the mass counterbalance system rendering it safe to work on during maintenance.

Leakage fluid conduits 29, 30 and 31 place the landing valve 28, the first and second fluid pumps (A, B), and fluid seals (not shown) within the end wall 19 of the retract chamber 7, in fluid communication with the fluid reservoir 21 of the fluid supply system 21 respectively.

The leakage fluid conduits 29, 30 or 31, are placed in such suitable fluid communication with the landing valve 28, the first and second fluid pumps (A, B), or fluid seals within the end wall 19 of the retract chamber 7, as the case may be, so as to enable hydraulic fluid which leaks from those components during use of the actuator to be collected at the fluid reservoir 21 of the fluid supply system for ultimate return to the fluid circuit of the actuator.

It is to be noted that the actuator system illustrated in figure 4 may be modified, in a further embodiment of the present invention, such that the hydraulic accumulator 17 of the system is placed in fluid communication with the fluid circuit of the actuator at a point along the fluid

conduit 27 of the fluid supply system between the one-way valve 26 and the landing valve 28 thereof. In this way, the hydraulic accumulator may be integrated as a part of the fluid supply unit of the actuator system as a whole, rather than being separate (but not separated) from the fluid supply unit as is the case in the embodiment illustrated in figure 4. The advantage of this alternative arrangement lies in the ability of the fluid supply unit 20 (including a single hydraulic accumulator arranged as discussed above) to supply hydraulic fluid to a plurality of separate actuator cylinders 6 and a plurality of associated first and second fluid pumps (A,B). This obviates the need not only for a fluid supply unit for each of the plurality of actuator cylinders (and their pumps), but also obviates the need for a corresponding plurality of separate dedicated hydraulic accumulators.

The end wall 19 includes a hydrostatic gland bearing arranged to provide a sealing bearing surface for the actuator rod 8 extending from the actuator. The function of conduit 32 in figure 4 is to supply a hydrostatic gland bearing (at end wall 19) with pressurised oil essential for its correct functioning. This bearing supports the rod 8 concentrically to the primary bore of the actuator by means of a very thin film of oil

maintained by a constant flow of pressurised oil, similar to plain bearings on an engine crankshaft but working to much smaller clearances and flow. This arrangement contributes the smallest possible frictional drag. A system pressure feed, in this case from the pre-charge system 20 (pump 24 & accumulator 17) is applied to the centre of the bearing, where the clearance is greatest, and flows in both directions, into the annular chamber 7 if pressure in there is lower and also to the drain line 30. Residual oil in the gland is sealed by a low friction elastomeric seal and this residual leakage is also returned to reservior via drain line 30. The two leakage paths are shown on figure 4.

Leakage can also occur from chamber 7 into feed line 32 if the pressure in chamber 7 is higher. It is this interchange of fluid at the hydrostatic bearing which prevents very high peak pressures being generated in chamber 7 as a result of small volumetric errors that might occur through leakage or pump wear.

To summarise, beneficial effects of the pre-charge system 20 are:

A Pressure spikes in chamber 7 are trimmed through leakage past the bearing into line 32;

B At zero or small motion activity the leakage flow will stabilise pressures in both sides of the actuator

i.e. chambers 7 & 10. Therefore there will be no leakage across piston 9 nor from line 32 into chamber 7;

C Leakage i.e. inefficiency is therefore restricted to leakage from line 32 across the bearing into drain line 30. Obviously this leakage path should be kept as small as possible, consistant with the correct functioning of the bearing.

The connection of pump B to an accumulator allows the differential volume between the extend and retract chambers to be displaced into the accumulator at a pressure. The stored pressure will backdrive pump B so that it behaves as a motor whenever the pressure in conduit 15 is less than in conduit 16. The pre-charge unit will pressurise the system until full mass counterbalance of the suspended load is achieved. In this state little or no input power from the servo motor (via pumps A & B) will be needed and significant energy savings can be made.

It is to be understood that variants of and modifications to any one of the embodiments described above, such as would be readily apparent to the skilled person, may be made without departing from the scope of the present invention.

Claims:

1. An actuator having:

an actuator chamber containing a moveable actuator piston and an actuator rod connected to the actuator piston and retractably extendable from the actuator;

the actuator chamber and actuator piston defining an extend chamber and a retract chamber separated from the extend chamber by the actuator piston such that the actuator rod extends through the retract chamber;

a fluid supply means arranged to supply fluid simultaneously to both the extend and retract chamber at substantially the same pressure and to reversibly transfer said pressurised fluid between the extend and retract chambers of the actuator.

2. An actuator according to Claim 1 in which the fluid supply means is operable to control the mutual fluid pressure of the fluid supplied thereby to the extend and retract chambers to be sufficient to enable the actuator to support a load applied to the actuator in use.

3. An actuator according to Claim 1 or Claim 2 in which the fluid supply means is arranged to reversibly transfer said pressurised fluid between the extend and retract chambers of the actuator, and to separately and

independently reversibly transfer said pressurised fluid between the extend chamber and a pressurised fluid store means.

4. An actuator according to Claim 1 or Claim 2 or Claim 3 in which the fluid supply means is arranged to transfer between the extend and retract chambers volumes of pressurised fluid substantially equal to a change in the volume of the retract chamber.

5. An actuator according to Claim 4 in which the fluid supply means is arranged to simultaneously transfer to and from the extend chamber volumes of pressurised fluid substantially equal to the change in the volume of the extend chamber less the concurrent change in the volume of the retract chamber.

6. An actuator according to any preceding claim in which the fluid supply means includes a first fluid transfer means in fluid communication with the extend chamber and the retract chamber and arranged to transfer therebetween volumes of fluid substantially equal in magnitude to changes in the volume of the retract chamber resulting from movement of the actuator piston within the actuator chamber;

and a second fluid transfer means in fluid communication with the extend chamber and operable to transfer to and from the extend chamber volumes of fluid substantially equal in magnitude to the difference between said changes in the volume of the retract chamber and concurrent changes in the volume of the extend chamber.

7. An actuator according to Claim 6 wherein the first fluid transfer means is a reversible first fluid pump, and the second transfer means is a reversible second fluid pump whereby the second pump is arranged to pump fluid at a volumetric rate determined according to the volumetric pump rate of the first pump.

8. An actuator according to Claim 7 in which the actuator chamber, actuator piston and those parts of the actuator rod within the actuator chamber define a retract chamber of substantially annular volume, whereby the ratio of the concurrent volumetric pump rates of the second and first pumps is substantially equal to the ratio of: changes in the volume of those parts of the actuator rod within the retract chamber; and, the corresponding changes in the annular volume of the retract chamber.

9. An actuator according to any of preceding claims 6 to 8 in which the second fluid transfer means is in fluid communication with a fluid vessel and is arranged to transfer fluid from the extend chamber to the fluid vessel and vice versa, wherein the fluid vessel is arranged to hold fluid received thereby from the second fluid transfer means in a state sufficiently pressurised to generate a back-pressure upon the second fluid transfer means which partially resists the flow of fluid from the second fluid transfer means to the fluid vessel.

10. An actuator according to Claim 9 wherein the fluid vessel is a fluid conduit connecting the second fluid transfer means in fluid communication with, and terminating at, a hydraulic accumulator.

11. An actuator according to claim 9 or claim 10 wherein the second transfer means is a reversible fluid pump and said fluid vessel is arranged to generate said back-pressure being sufficient to urge the reversible fluid pump of the second transfer means to back-drive thereby to urge the pump to operate to pump fluid from the fluid vessel to the extend chamber.

12. An actuator according to any of proceeding

claims 9 to 11 wherein said fluid vessel is operable to be in fluid communication with said first fluid transfer means via said second fluid transfer means.

13. An actuator according to any of claims 9 to 12 including a fluid supply operable to be in fluid communication with and to supply pressurised fluid to said fluid vessel, said first fluid transfer means, said second fluid transfer means, and said actuator chamber.

14. A method of actuation for use with an actuator having an actuator chamber containing a moveable actuator piston and an actuator rod connected to the actuator piston and retractably extendable from the actuator, the actuator chamber and actuator piston defining an extend chamber and a retract chamber separated from the extend chamber by the actuator piston such that the actuator rod extends through the retract chamber, the method including:

supplying fluid simultaneously to both the extend and retract chamber at substantially the same pressure and reversibly transferring said pressurised fluid between the extend and retract chambers of the actuator.

15. A method according to Claim 14 including

controlling the mutual fluid pressure of the fluid supplied to the extend and retract chambers to be sufficient to enable the actuator to support a load applied to the actuator in use.

16. A method according to Claim 14 or 15 including reversibly transferring said pressurised fluid between the extend and retract chambers of the actuator, and separately and independently reversibly transferring said pressurised fluid between the extend chamber and a pressurised fluid store means.

17. A method according to Claim 14, 15 or 16 including transferring between the extend and retract chambers volumes of pressurised fluid substantially equal to a change in the volume of the retract chamber.

18. A method according to Claim 17 including simultaneously transferring to and from the extend chamber volumes of pressurised fluid substantially equal to the change in the volume of the extend chamber less the concurrent change in the volume of the retract chamber.

19. A method according to any of Claims 14 to 18

including transferring between the extend chamber and the retract chamber volumes of fluid substantially equal in magnitude to changes in the volume of the retract chamber resulting from movement of the actuator piston within the actuator chamber;

transferring to and from the extend chamber volumes of fluid substantially equal in magnitude to the difference between said changes in the volume of the retract chamber and concurrent changes in the volume of the extend chamber.

20. A method of actuation according to Claim 19 wherein fluid is transferred between the extend chamber and the retract chamber by the reversible pumping thereof at a first volumetric pump rate, and fluid is transferred to and from the retract chamber by the reversible pumping thereof at a second volumetric pump rate determined according to the first volumetric pump rate.

21. A method of actuation according to Claim 20 in which the actuator chamber, actuator piston and those parts of the actuator rod within the actuator chamber define a retract chamber of substantially annular volume, whereby the ratio of the concurrent second and first volumetric pump rates is substantially equal to the ratio of: changes in the volume of those parts of the actuator

rod within the retract chamber; and, the corresponding changes in the annular volume of the retract chamber.

22. A method of actuation according to any of preceding claims 19 to 21 including holding fluid transferred from, or to be transferred to, the extend chamber in a state sufficiently pressurised to generate a back-pressure which partially resists the transfer of fluid from the extend chamber.

23. A method of actuation according to claim 22 including providing a reversible fluid pump arranged to perform said transfer of fluid to and from the extend chamber by pumping said fluid, and generating said back-pressure to be sufficient to urge the reversible fluid pump to back-drive thereby to urge the pump to operate to pump said held fluid to the extend chamber.

24. A method of actuation according to any of proceeding claims 22 to 23 including holding said held fluid in fluid communication with said extend chamber and said retract chamber.

25. A method of actuation according to any of preceding claims 19 to 24 for use in providing simulated motion in a vehicle simulator machine.

26. A motion platform for a vehicle motion simulator machine including an actuator according to any of claims 1 to 13.

27. A vehicle motion simulator including a motion platform according to Claim 26.

28. An actuator substantially as described in any one embodiment hereinbefore with reference to the accompanying drawings.

29. A method of actuation substantially as described in any one embodiment hereinbefore with reference to the accompanying drawings.

Abstract

Apparatus and method for actuation

There is disclosed an actuator (5) having an actuator chamber (6) and actuator piston (9) therein defining an extend chamber (10) and a retract chamber (7) separated from the extend chamber by the actuator piston. A first fluid pump (A) is in fluid communication with the extend chamber and the retract chamber and is arranged to transfer therebetween volumes of fluid substantially equal in magnitude to changes in the volume of the retract chamber resulting from movement of the actuator piston within the actuator chamber. A second pump B connected to the extend chamber and to an accumulator (17) allows the differential volume between the extend and retract chambers to be displaced into the accumulator at a pressure. Stored accumulator fluid pressure enables pump B to be back-driven so that it behaves as a motor whenever the pressure in conduit 15 is less than in conduit 16. A pre-charge (20) unit pressurises the system until full mass counterbalance of the suspended load is achieved. In this state little or no input power from the servo motor (via pumps A & B) will be needed and significant energy savings can be made.

[Figure 3]

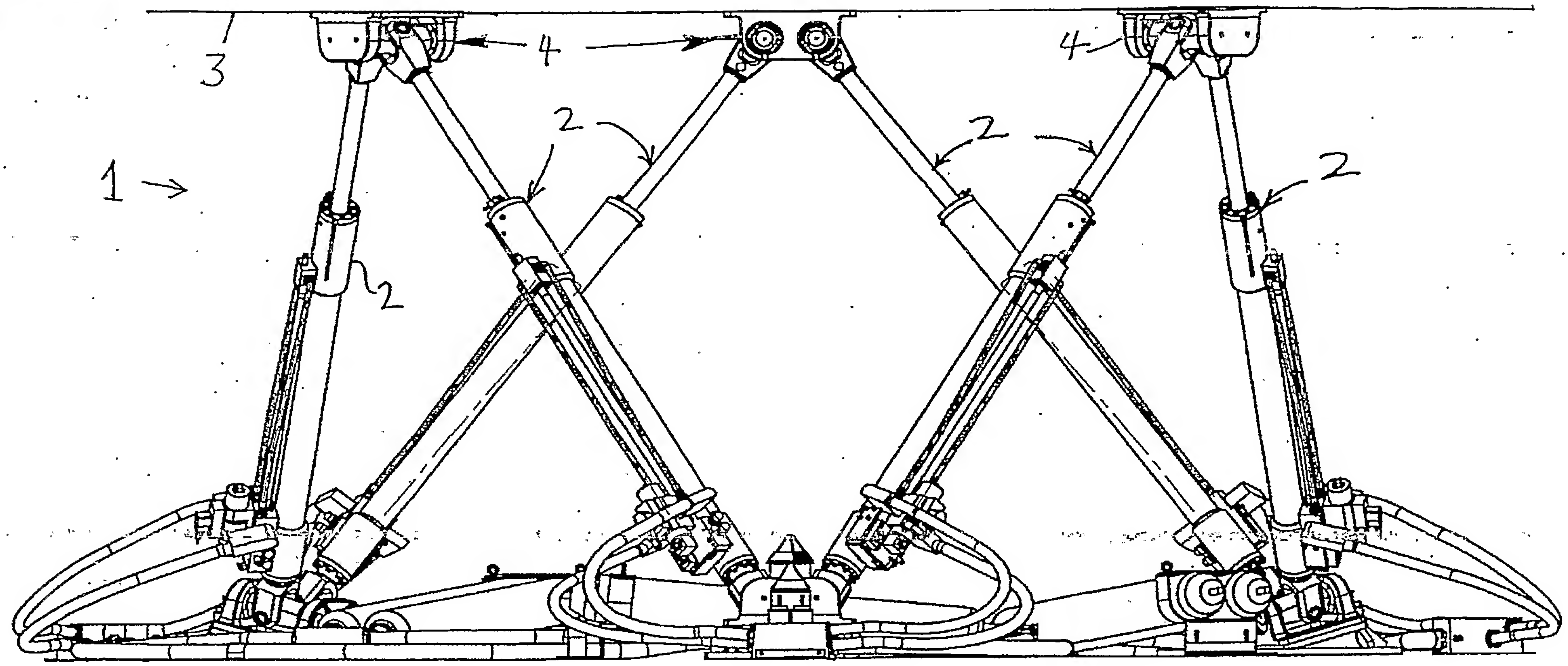

FIGURE 1

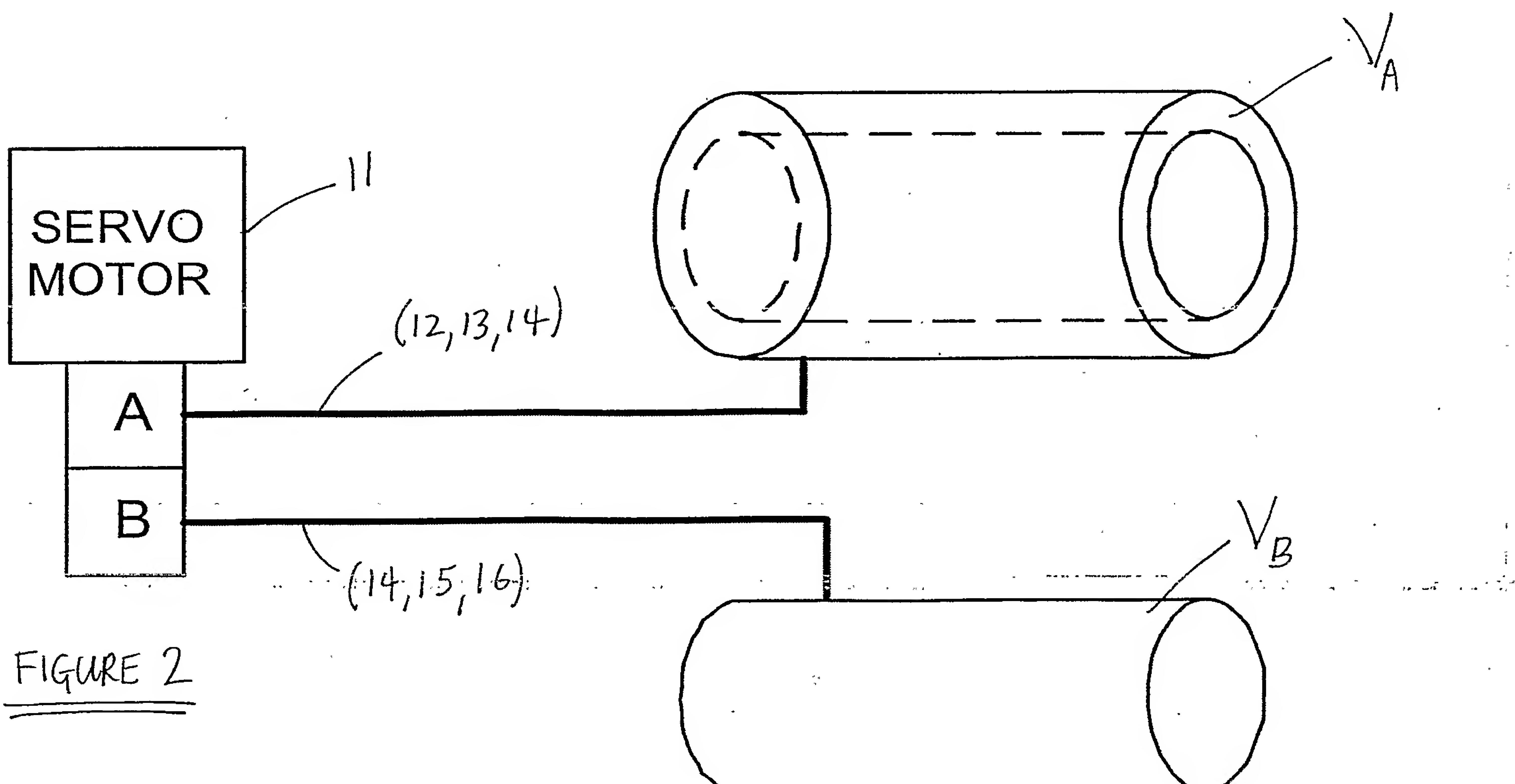

FIGURE 2

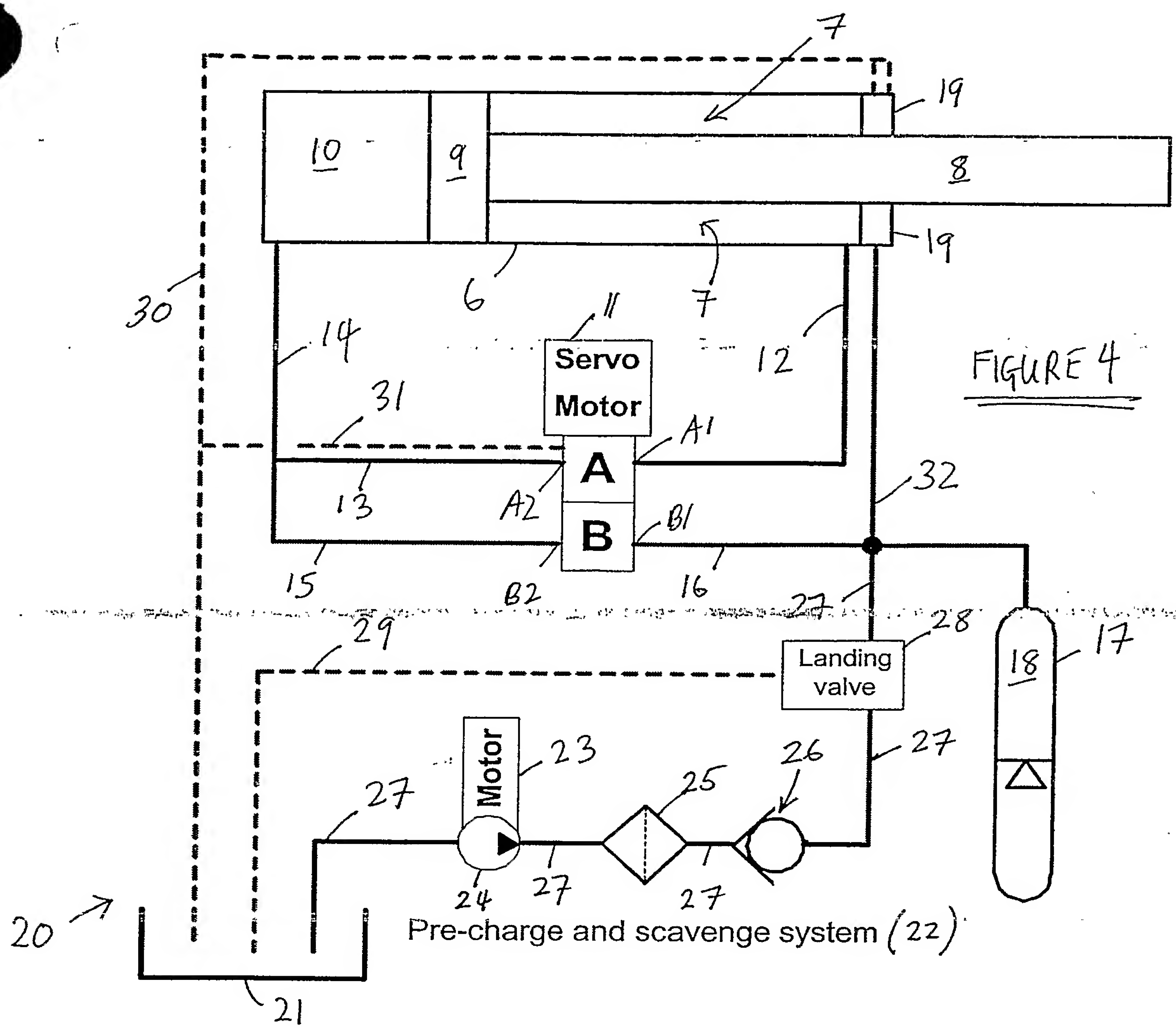

FIGURE 4

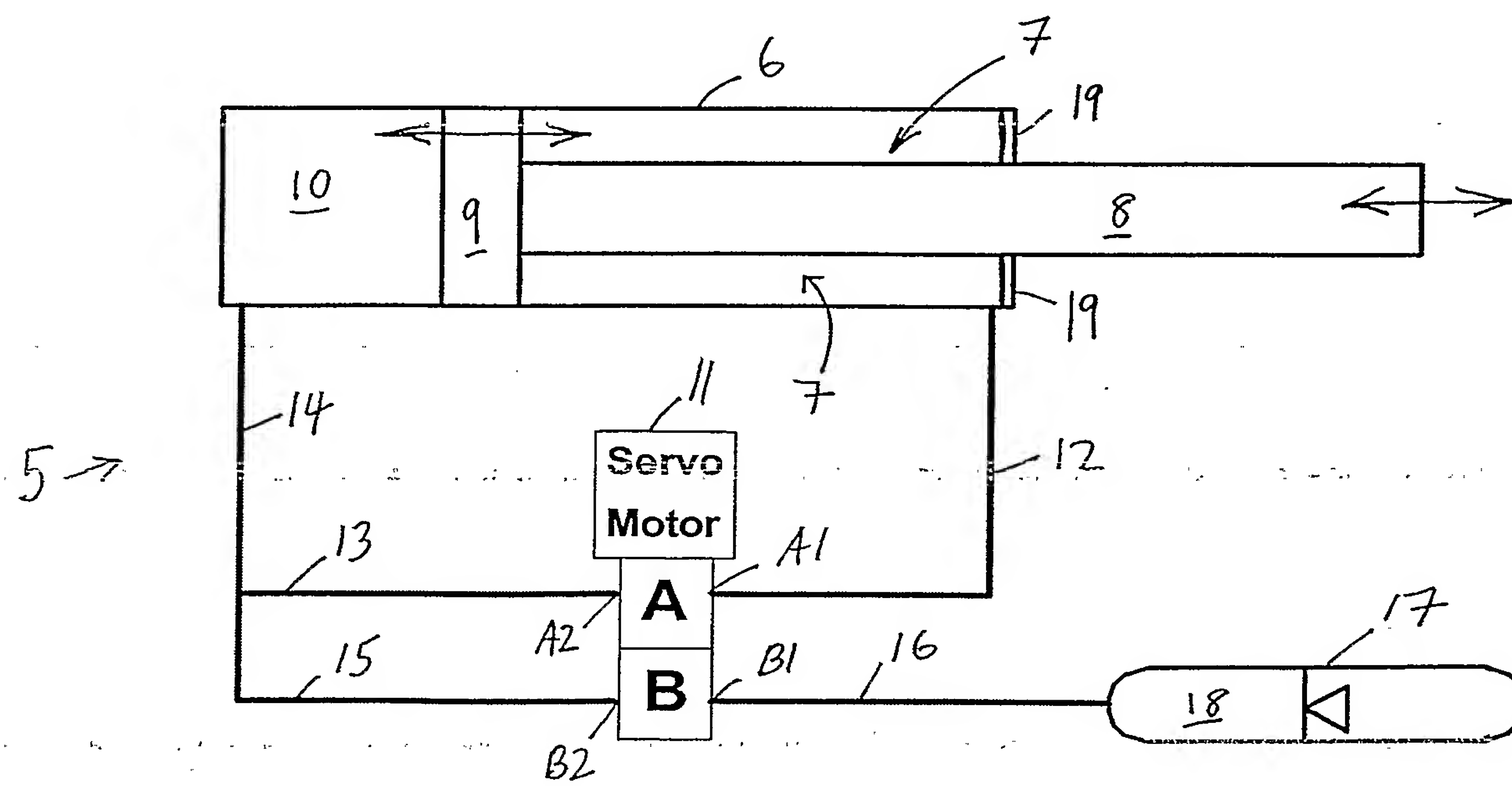

FIGURE 3

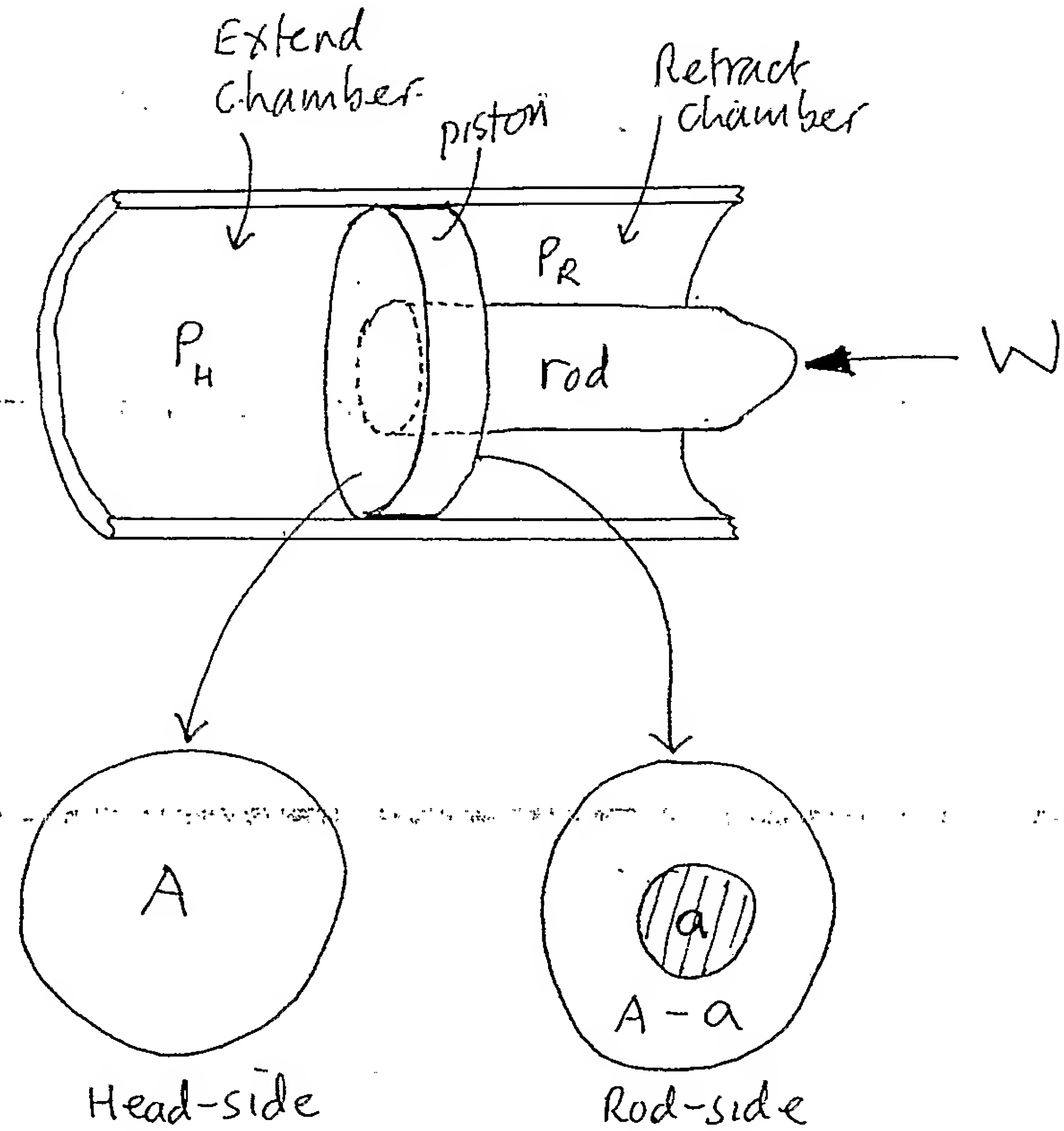
Extend Chamber
piston
Retract chamber
P_R
P_H
rod
W
A
a
A − a
Head-side
Rod-side

Figure 5